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**STUDY OF THE SUB- AND SUPERCRITICAL BEHAVIOR OF FUEL
DROPLETS AND JETS**

Technical Progress Report

For the Period April 1, 1998 -- August 31, 1998

For

Contract No. F49620-98-1-0373

Air Force Office of Scientific Research
Directorate of Aerospace and Materials Sciences
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ABSTRACT

A project to conduct experiments to understand the flow and thermodynamic characteristics of liquid fuel droplets and jets in subcritical and supercritical environments was initiated. In the project initiation phase (Phase I), the literature on the subject matter was updated, the experimental setup was designed and modifications in the setup including installation of thermocouples, pressure transducers and analytical and diagnostic devices (LDV, PIV and high speed video imaging systems) were either initiated or completed. Preliminary experiments on suspended and free falling hexane droplet gasification and combustion under subcritical and supercritical pressure conditions were undertaken. The preliminary results were very interesting and promising especially with respect to the variation of gasification rate with increasing pressure and decreasing droplet size and the effect of buoyancy on the burning droplet. The project remained slightly ahead of schedule at the end of the reporting period

PROJECT TASKS AND ACCOMPLISHMENTS

The project has been scheduled into three phases. Phase I, which covers the current reporting period, serves as the project initiation phase. This phase of study includes the following tasks and deliverables and is to be completed by April, 1999:

1. Literature updating;
2. Experimental setup design;
3. Initiation of the modification of CAU experimental setup including installation of thermocouple, pressure transducers, and other analytical instrumentation; and
4. Installation, testing and calibration of LDV, PIV, and high speed imaging system.

To date, all of the planned activities as described in the project plan have either been completed or started on schedule. Summaries of the activities and accomplishments for this period for each of the above tasks are given below.

Literature Updating

Further literature survey has been conducted since the award of the contract. This task was completed with the help of Dr. Doug Talley from the AFRL, who provided a 200-paper bibliography on supercritical droplet vaporization and combustion. This literature updating provided some additional information about the current research activities and problems in the field. However, the major conclusions remain the same as those described in the project proposal.

Experimental Setup Design

The experimental set-up is shown in Fig. 1, and consists of a liquid-fuel supply system, a gas pressure-control system, a droplet formation system, a high-pressure chamber, an electrical ignitor, and a high-speed CCD video system.

Liquid Fuel Supply System

The liquid fuel supply system consists of a liquid-fuel reservoir, and a high pressure liquid pump (Eldex Laboratories, Inc., Model B-100-s). The liquid pump operates up to 1500 psi at flow rates from 0 to 150 mL/min. The liquid was transferred by stainless steel tubing. The flow rate was adjusted by the liquid pump and an inlet needle valve between the system and the combustion chamber.

Droplet Formation and Release System

The droplet system developed at CAU consists of a 200×1 -mm-o.d. ceramic tube which had four 0.2-mm-i.d. holes in its axial direction. At the position of 30 mm from one end, the wall of the ceramic tube was cut to expose two of the four holes (Fig. 2). The two wires of a thermocouple were inserted into the two holes of the ceramic tube, and introduced out from the two cuts on the tube wall, where the tip of the thermocouple was left about 10 mm from the end of the ceramic tube. The ceramic tube was then inserted into a 1/8" stainless steel tube which also had two cuts on its wall for the thermocouple wire to go through. The cuts were sealed by high temperature cement. The stainless steel tube was vertically mounted on the top of the combustor, while the ceramic tube was connected to 1/16 stainless steel tubing of the liquid feeding system by a stainless steel union.

The pressurized liquid fuel was introduced to the other two unused holes of the ceramic tube. The fuel flowed out of the other end to form a 1.5-mm-dia droplet at the tip of the thermocouple. The rate of droplet formation was controlled by the liquid flow rate.

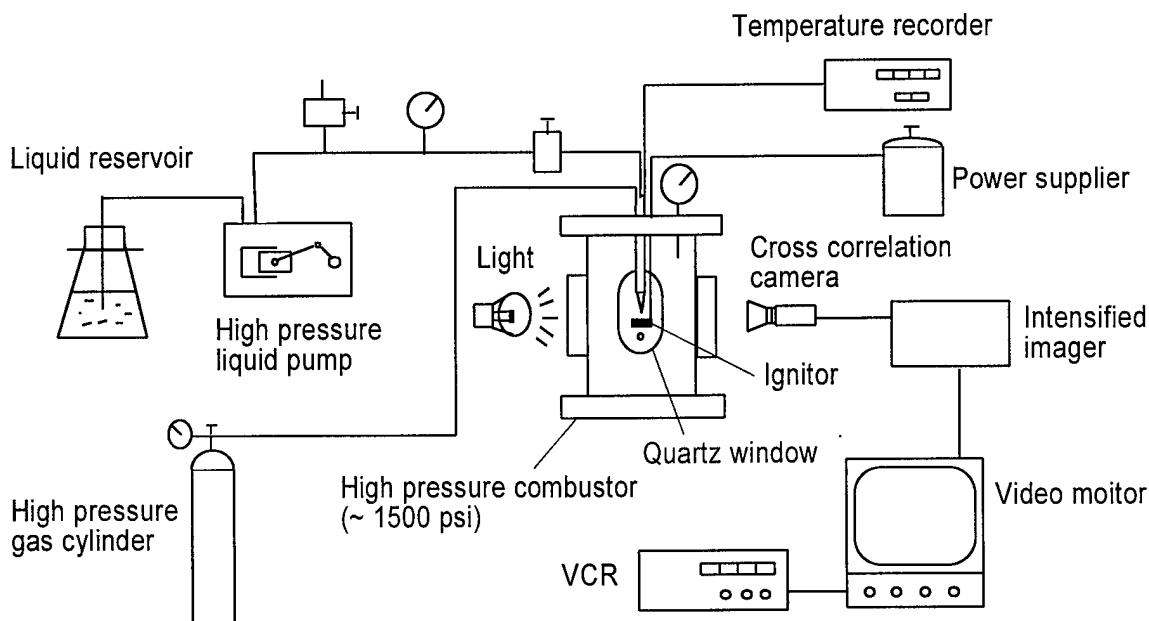


Fig. 1 Schematic of the experimental setup.

High Pressure Chamber

The chamber was cylindrical and had a test section of 450 mm (high) \times 95 mm (dia.), with four quartz windows of 90 mm (high) \times 38 mm (wide). The chamber was pressurized [up to 1500 psi (10.3 MPa)] by a bottle gas.

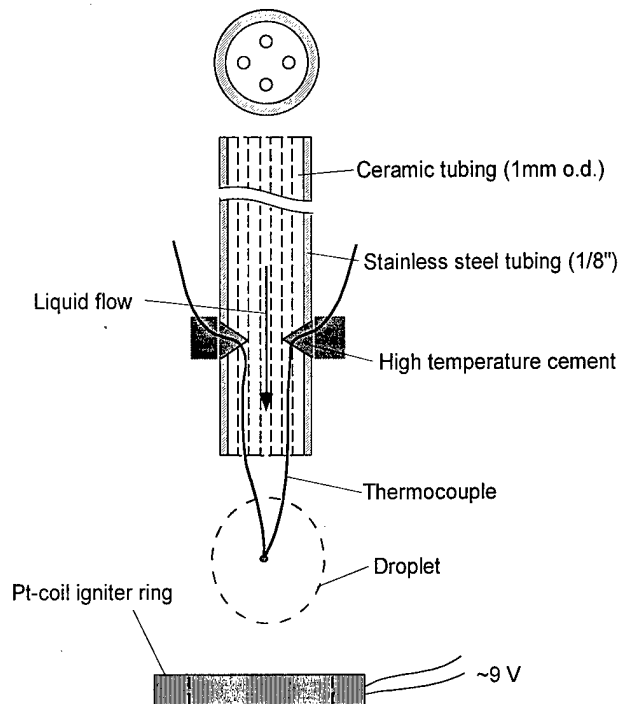


Fig. 2 Diagram of the droplet formation system and ignitor.

Electrical Ignitor

The ignitor consisted of a filament and power supply. The filament was made from a coiled 0.8 mm dia. platinum wire, and was wound into a 4-mm-i.d. ring, which was mounted 20 mm below the tip of the thermocouple. The ignitor ring was carefully aligned so that the free droplet from the thermocouple passed through without touching the ring (Fig. 2). The temperature of the ignition filament was controlled from ambient to 1400 °C by adjusting the supplying voltage. About 800 °C was found to be high enough to ignite the hexane free droplet in this study, where the power supply voltage was about 7 V a.c.

Optical Measurement System

The optical measuring system consisted of a micro lens (Micro-Nikkor, 200 mm, 1:4, Nikkor) and a high-speed image system (Kodak). The imaging system included an EktaPro Intensified Imager and a EktaPro Hi-Spec Processor. All of the images were continuously taken at the speed of 1000 frame per second (fps) with the exposure time of $\sim 30 \mu\text{s}$.

Experimental Procedure

The experiments were conducted using the following procedure: (1) The combustion chamber with gas (air/N₂) was pressurized to a desired value. (2) The liquid pump was started, and the liquid fuel was pressurized. (3) For the gasification rate measurements, a suspended droplet was used, and the procedure was as follows: the inlet needle valve on the liquid feeding line was opened; the flow rate was carefully adjusted until a droplet hung on the tip of the thermocouple; the needle valve was quickly closed; and the droplet image was recorded by the video system and the temperature change was measured through the thermocouple on which the droplet was suspended. (4) For the combustion test, a free droplet was used. When a droplet had formed at the tip of the thermocouple, the liquid flow rate was carefully adjusted to have the droplet drop. The video system and the ignitor were then turned on. While a free droplet was falling through the ignitor's filament ring, it was ignited. The burning droplet continuously fell or floated back according to the system pressure. The whole process was recorded by the high-speed video system, and it was analyzed.

Modification of CAU Experimental Setup

To simulate the supercritical temperature environment, the experimental setup needs to have the capability of heating the gaseous environment and the liquid fuel to temperatures exceeding the critical temperature of the liquid fuel to be tested. The modification of the experimental setup mainly consists of adding electrical heating element and the necessary control mechanisms in the gaseous and liquid feed systems. Design of the modification has been completed and purchase requisitions have been prepared to acquire the needed equipment and parts.

Installation, Testing and Calibration of LDV, PIV, and High Speed Imaging System

Measurement systems have been installed and tested. Among them, the 3D LDV system and the PIV system have been utilized to conduct simulated flow field measurements to prepare the researchers with their operation and potential problems. The high speed imaging system has been successfully tested using the developed droplet experimental setup. Preliminary studies of the high speed images obtained have shown very interesting and promising results especially with respect to the effects of increasing pressure and decreasing droplet size on the gasification and combustion of suspended and free falling hexane droplets. The observed reversal from falling droplet to rising burning droplet under some experimental conditions showed the interesting effect of buoyancy.

PLANS FOR THE NEXT REPORTING PERIOD

In the next reporting period, the following tasks will be undertaken:

- Continuation and completion of the experimental setup modification.
- System integration and synchronization.
- Data and image processing software development.
- System shake-down and detailed experiments with heptane
- Joint experiments with AFRL on jets.

PERSONNEL SUPPORTED

The project supported Dr. Yaw D. Yeboah (PI), Dr. Tiejun Bai (Co-PI), and Dr. Jason Nie (Research Scientist). In addition, two undergraduates worked on the project.

PUBLICATIONS

No journal paper on the project was published in this period.

PRESENTATIONS

A presentation was given in the 1998 Technical Meeting of Central State Section of the Combustion Institute on June 1 at Lexington, Kentucky. The paper was entitled "Preliminary Study of Droplet Gasification and Combustion Characteristics Under Sub and Supercritical Pressure Environments." A technical project status report/presentation was made at the Joint ARO/AFOSR Contractors' meeting in Chemical Propulsion, Long Beach, CA, June 29- July 1, 1998.

INTERACTIONS RELATED TO THE RESEARCH

Joint experiments have been planned with researchers at the Air Force Research Laboratory (Drs. Doug Talley and Bruce Chehroudi). The experiments will be conducted by CAU and Air Force scientists in California using Air Force droplet research facilities and the CAU high speed video imaging system.

INVENTION

There was no invention from this research in the reporting period.